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Brigham Young University
Department of Civil Engineering

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This is the third quarter progress report for the research project "HCMM Hydrological Analysis in Utah". During this period the temperature calibration and groundwater depth location studies were finalized. Distinctions among algae species and among suspended materials (turbidity) using HCMM data were investigated. Field evaluations of algae's effect on evaporation pan readings were also completed and related to the lake and HCMM data. Additional correlations among infrared and reflectivity data were made using the color graphics capabilities developed during this project.

No major problems have been encountered as the work is progressing normally. Completion of the final report which will contain many interesting and significant results is expected on schedule. Any comments regarding this brief update are welcome.

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HCMM HYDROLOGICAL ANALYSIS IN UTAH

THIRD QUARTER REPORT

Data Update

Since the second quarter report, no new data sets have been received. Three sets are missing and desired, but it appears that they won't arrive in time to be analyzed and incorporated in the study.

Water Quality Relationships

Most of the work accomplished during the third quarter was related to water quality detection and evaluation. In particular the relationships among algae, nutrients, turbidity, and HCMM data were investigated.

The correlations presented herein were developed according to standard methods with the raw HCMM and water quality data which will be included in the final report. The various correlation coefficients are compiled and presented in the individual tables as reference is made to them. Graphs of the regression lines representing several data sets are also given.

Day-Infrared and log Total Plankton

The DIR intensity nearest each lake sampling station was identified and included in the raw data for this correlation analysis.

The net plankton measurements taken on Utah Lake have been used to represent the algae concentrations present in 1978. The major reason for this is that more complete records were kept in 1978 of the net plankton counts on the lake than of the total or nanno plankton counts.

Since the accuracy of this investigation increases with an increase in the number of correlations made, the net plankton counts were chosen. Since no other data is available, these counts were assumed to be representative of the total plankton population in Utah Lake. They are hereafter referred to as plankton counts or plankton concentrations. Correlation of the total plankton counts was used for measurements made in 1979.

The plankton samples were taken at the lake sampling sites and enumerated according to the procedures presented previously. The correlation during the summer months of the algae concentration in Utah Lake and the emitted heat (DIR) from the water surface is very high for a naturally occurring system. Values are given in Table 1a which also includes the level of significance for each correlation. If the level of significance of the correlation (α) between the algae concentrations in the lake and the DIR was 0.005 this would mean that all but 0.5% of the distribution of the correlation could be interpreted as being significant in the substantiation of this relationship. If the significance of the correlation was greater than 0.05 the correlation was considered "not significant" and was designated by n/s.

Table 1a

Correlation Coefficient of DIR and log Total Plankton
1978

Date	07/28	08/03	08/10	08/17	08/23	09/13	10/14	10/25
Corr.	0.841	0.749	0.640	0.977	0.783	0.605	0.758	0.479
Sig.( )	0.005	0.01	0.025	0.005	0.005	0.05	0.005	n/s

As the algae concentration in the water increases it appears more like a land mass on the DIR printouts; i.e., collecting more heat during the daytime hours so that it appears warmer and then losing heat more rapidly than the clearer waters during the nighttime. This phenomenon can be observed very easily by comparing the day and night infrared data as displayed in the color pictures. The color pictures of the DIR and NIR data clearly show the same areas in Utah Lake being respectively warmer and cooler. It is the purpose of this report to present the results of the correlation analyses performed for this study. A presentation and complete description of the color pictures mentioned will be included in the final report.

The description of the waters concentrated with algae being similar to land bodies is valid since the same phenomenon is responsible for the behavior of each with respect to temperature. The addition of the algae to a mass of water has the effect of lowering the specific heat of the mass from the specific heat of clear water (1.00 cal/gm- C). Since the specific heat of land is also lower than 1.0, both the land and the algae concentrated water acquire and lose heat more rapidly than clear water. This makes possible the detection of algae concentrations in water bodies such as Utah Lake by monitoring the heat from the lake during the day and night. Figure 1 is a graphical representation of the linear regression of the DIR and log total plankton as measured on Utah Lake, July 28, 1978. The regression equation and the value of r are included.

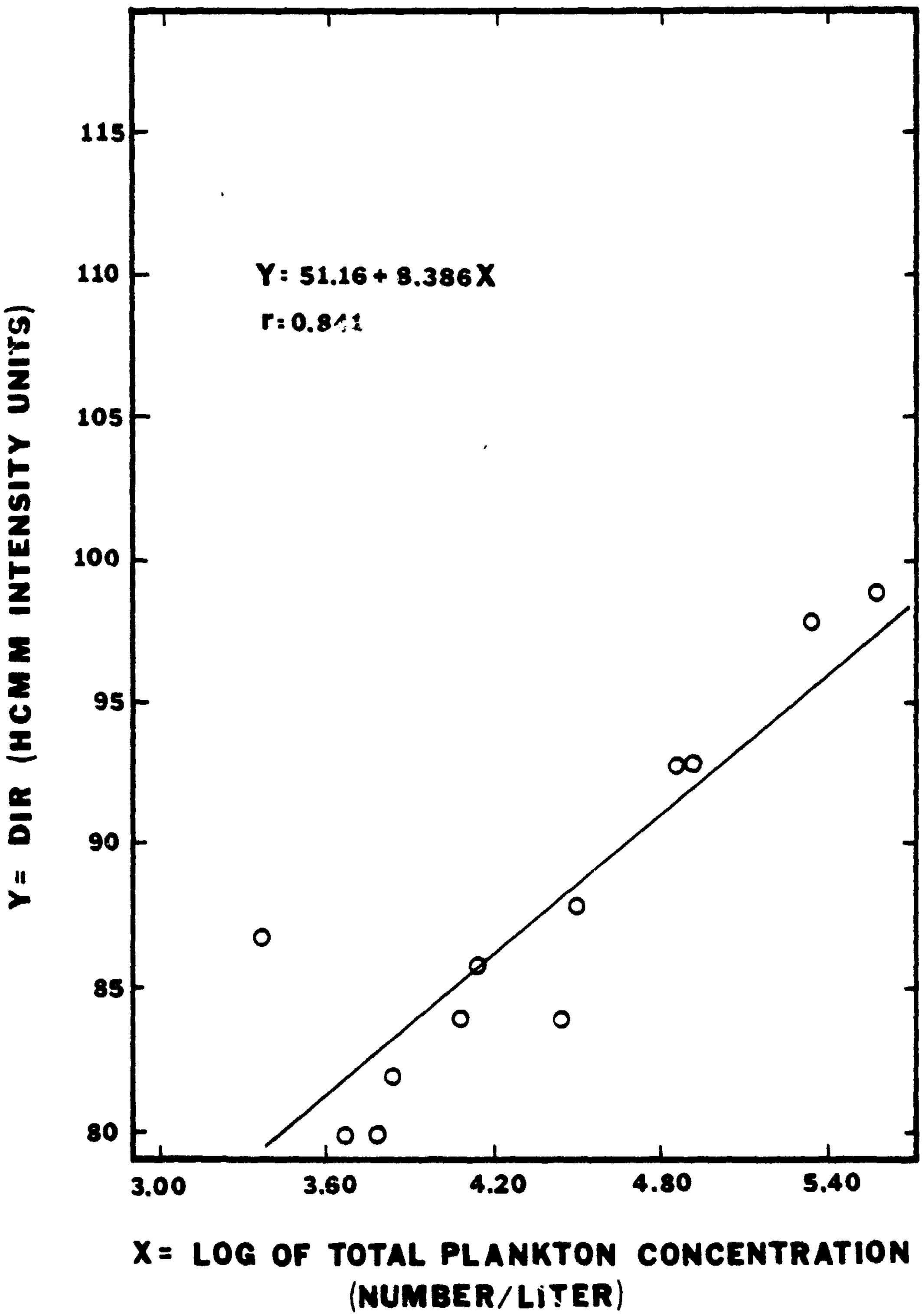

Figure 1. Plot of DIR and log of Total Plankton Concentrations on Utah Lake, August 17, 1978.

Day-Infrared and log Ceratium Hirundinalla

Ceratium hirundinella (Figure 2) is a solitary, unicellular plant. Its cells are generally narrowly fusiform with one apical horn and 2 or 3 stouter and shorter basal horns. The cells are 30 to 72 m wide and 100 to 400 m long (on the average). Although rare in early June on Utah Lake, this algae was one of the dominant plankton throughout the rest of the summer. It was often abundant enough to color the water muddy-brown and plug plankton nets during sampling operations. Correlation and significance levels for CH are given in Table 1b below.

Table 1b

Correlation Coefficients of DIR and log of Ceratium Hirundinella Concentration 1978

Date	07/28	08/03	08/10	08/17	08/23	09/13
Corr.	0.754	-0.224	0.220	0.533	-0.176	0.705
Sig.(α)	0.01	n/s	n/s	n/s	n/s	0.025

No real, continuous relationship could be established between the Ceratium hirundinella population in Utah Lake and the emitted heat (DIR) from the water surface. The most probable reason for this is that the Ceratium do not form clumps or clusters which would increase their density in the water and therby increase both heat conductivity and storage. Another important observation is that while Ceratium is the second most dominant alga in the lake it constitutes less than 10% of the total alga count in the later summer months. This results in

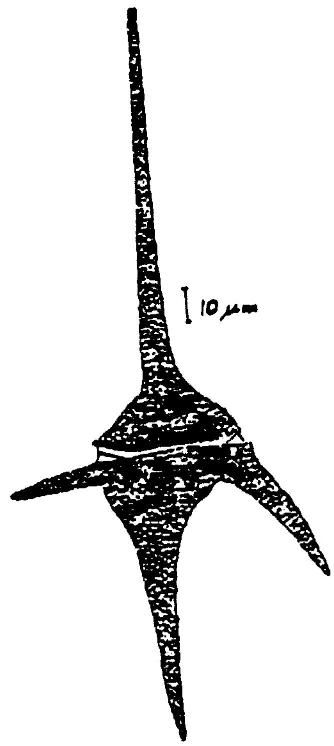

Figure 2. Ceratium hirundinella.

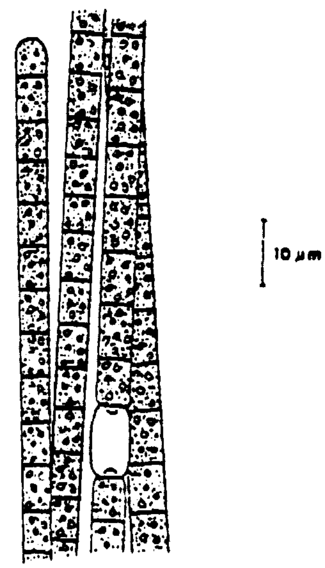

Figure 3. Afanizomenon flos-aquae.

the Ceratium not having much effect on the observable heat emitance compared to the entire plankton mass.

Day-Infrared and log Afanizomenon Flos-Aquae Concentration

Afanizomenon flos-aquae (Figure 3) is a parallel trichomes algae, united in bundles or flakes to form macroscopic aggregates. Its apices are broadly rounded, not attenuate, with cells 5 to 6 m in diameter and 6 to 8 m long. Afanizomenon contains numerous conspicuous pseudovacoules and oblong or cylindrical heterocysts not found on the Ceratium. This blue-green algae was usually the most abundant and conspicuous summer plankton in Utah Lake. Table 5.1c shows correlations and significance levels for DIR and AFA.

Table 1c

Correlation Coefficients of DIR and log Afanizomenon Flos-Aquae Concentration 1978

Date	07/28	08/03	08/10	08/17	08/23	09/13	10/14	10/25
Corr.	0.993	0.728	0.628	0.987	0.783	0.599	0.767	0.503
Sig.(α)	0.005	0.01	0.025	0.005	0.005	0.05	0.005	n/s

An obvious relationship exists between the emitted heat from Utah Lake (DIR) in the summer and the Afanizomenon concentration in the lake. These correlations closely parallel those of total plankton which was expected since nearly 90% of the plankton count in Utah Lake in the late summer is Afanizomenon. This study does not attempt to explain the reasons for the change during the summer season from a large diversity of species of plankton to essentially only two by late

summer. Rather, this phenomenon is noted and has been substantiated by the similarity of the Afanizcmenon and total plankton correlations with the DIR measurements. Figure 4 is the graph of the linear regression analysis performed on the DIR and log of the net Afanizomenon count which illustrates this relationship.

Visual Reflectivity and log Total Plankton

The HCMM visual reflectivity measurements (VR) were made by the satellite and tabulated for this comparison as explained in previously. The VR intensity nearest each station where lake measurements were made was recorded and is included in the raw data tables to follow. Table 5.1d below gives the correlations and significance of VR and plankton relationships.

Table 1d

Correlation Coefficients of VR and log Total Plankton Concentration 1978

Data	07/28	08/03	08/10	08/17	08/23	09/13	10/14	10/25
Corr.	-0.960	-0.946	-0.972	-0.979	-0.652	-0.740	-0.190	0.005
Sig.(α)	0.005	0.005	0.005	0.005	0.025	0.025	n/s	n/s

During the early summer and on through the middle of August a very high negative correlation exists between the algae concentration in the lake waters and the reflectivity of the lake surface. This negative correlation indicates that as the concentration of the algae increases in the Utah Lake waters the reflectiveness of the water surface decreases or appears darker. Figure 5 is a representation of the regression of the VR and log Total Plankton on August 17, 1978.

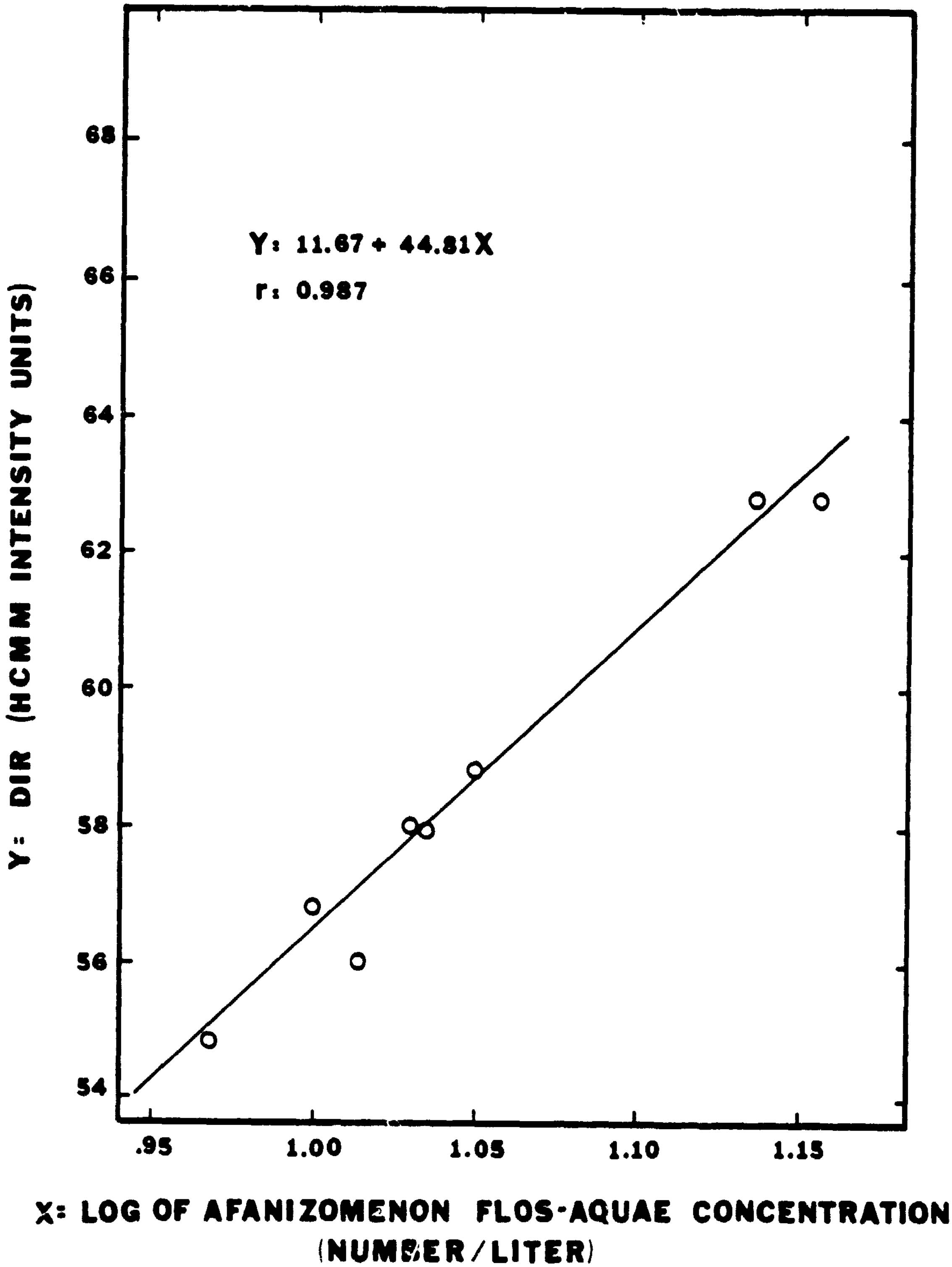

Figure 4. Plot of DIR and log of Afanizomenon flos-aquae Concentrations in Utah Lake, August 17, 1978.

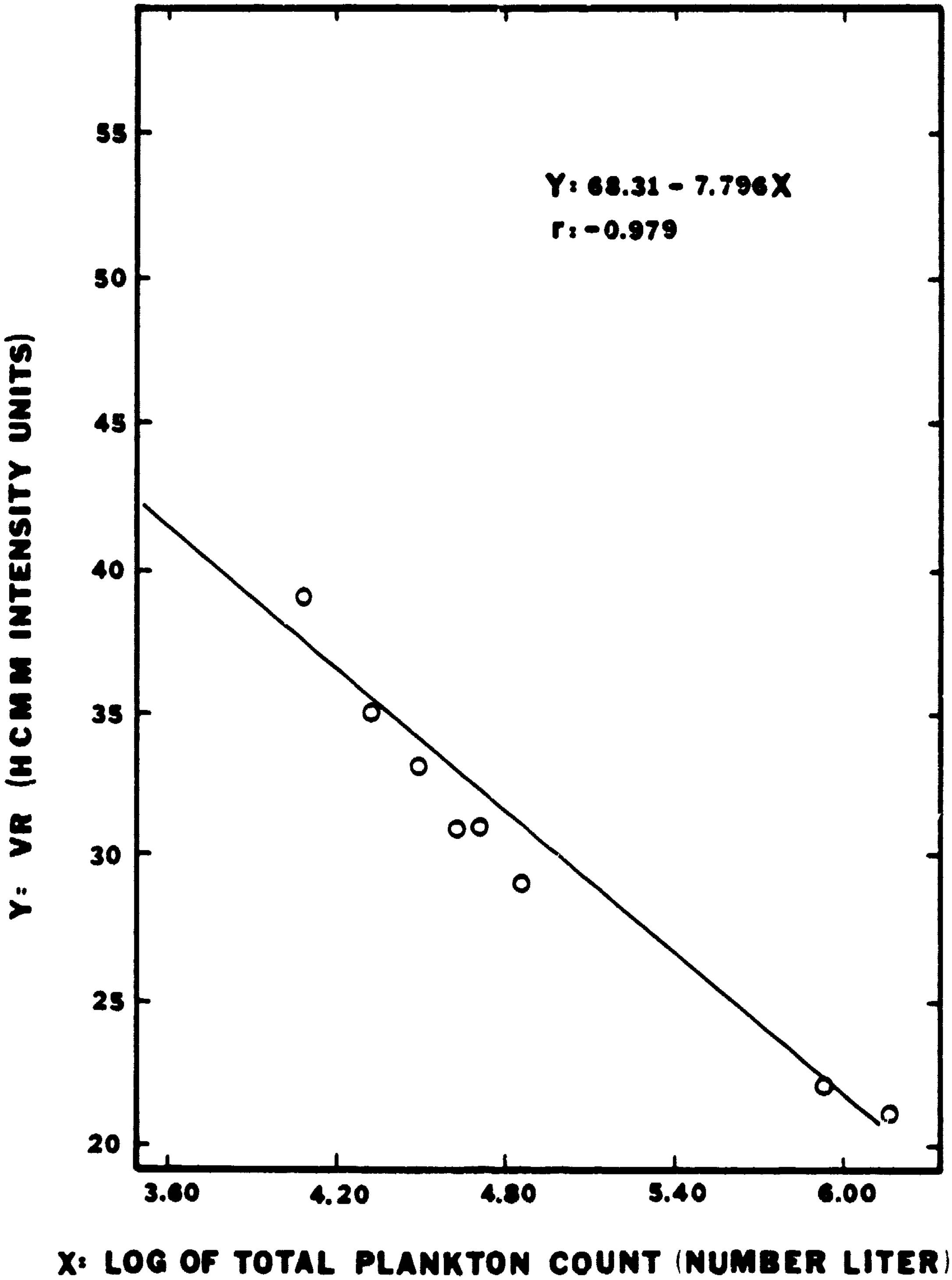

Figure 5. Plot of VR and log of Total Plankton Concentration on Utah Lake, August 17, 1978.

In late August this inverse relationship between VR and total plankton concentration decreases and by October there is essentially no relationship. The reason for the breakdown of this relationship appears to be the occurrance of blooms of algae on the lake surface. These whitish, floating matts of algae and air bubbles are very reflective. Development of these reflective blooms over the area of highest algae concentration which had previously been the least reflective areas on the lake effectively reduces the inverse correlation between the HCMM VR and the algae concentrations.

Visual Reflectivity and log of Ceratium Hirundinella Concentration

Table 1e

Correlation Coefficients of VR and log of Ceratium Hirundinella 1978

Date	07/28	08/03	08/10	08/17	08/23	09/13
Corr.	-0.883	-0.362	-0.467	-0.571	-0.313	-0.535
Sig. (α)	0.005	n/s	n/s	n/s	n/s	0.05

While some correlations between the VR and log of net Ceratium hirundinella count are quite significant, no continuous relationship could be established. The probable reasons for this are the same as those for which no continuous relationship could be established between Ceratium and DIR; i.e., the Ceratium cells do not join together to form larger bodies in the water and the proportion of the total plankton concentration made up by Ceratium is relatively small. This lack of correlation and significance are shown in Table 1e above.

Visual Reflectivity and log Afanizomenon Flos-Aquae Concentration

Table 1f

Correlation Coefficients of VR and log Afanizomenon Concentration 1978

Date	07/28	08/03	08/10	08/17	08/23	09/13	10/14	10/25
Corr.	-0.945	-0.886	-0.949	-0.994	-0.645	-0.731	-0.214	-0.005
Sig.(α)	0.005	0.005	0.005	0.005	0.025	0.025	n/s	n/s

Because the correlation analysis for VR and Afanizomenon shown in Figure 1f doesn't give a different pattern of results than that given for VR and total plankton, a conclusion could not be reached about the reflective properties of Afanizomenon as compared with the total phytoplankton in Utah Lake. The decline in the inverse correlation beginning in late August is caused by the same phenomenon, algal blooms, which is responsible for the decline in the relationship between VR and the total plankton concentration. Figure 6 shows a graph of the linear regression of VR on the log of Afanizomenon flos-aquae concentrations in Utah Lake, August 10, 1978.

Phosphorus and log Total Plankton Concentrations and log Afanizomenon Flos-Aquae

Analyses were made on samples of Utah Lake waters taken at the lake measuring stations to determine the amount of phosphorus present in the sample. These analyses were made in the Brigham Young University Water Research Laboratory and were recorded in the unpublished WHAB Lab Reports of 1977-1979. The measurements of phosphorus concentration which coincide with the algae and HCMM measurements made

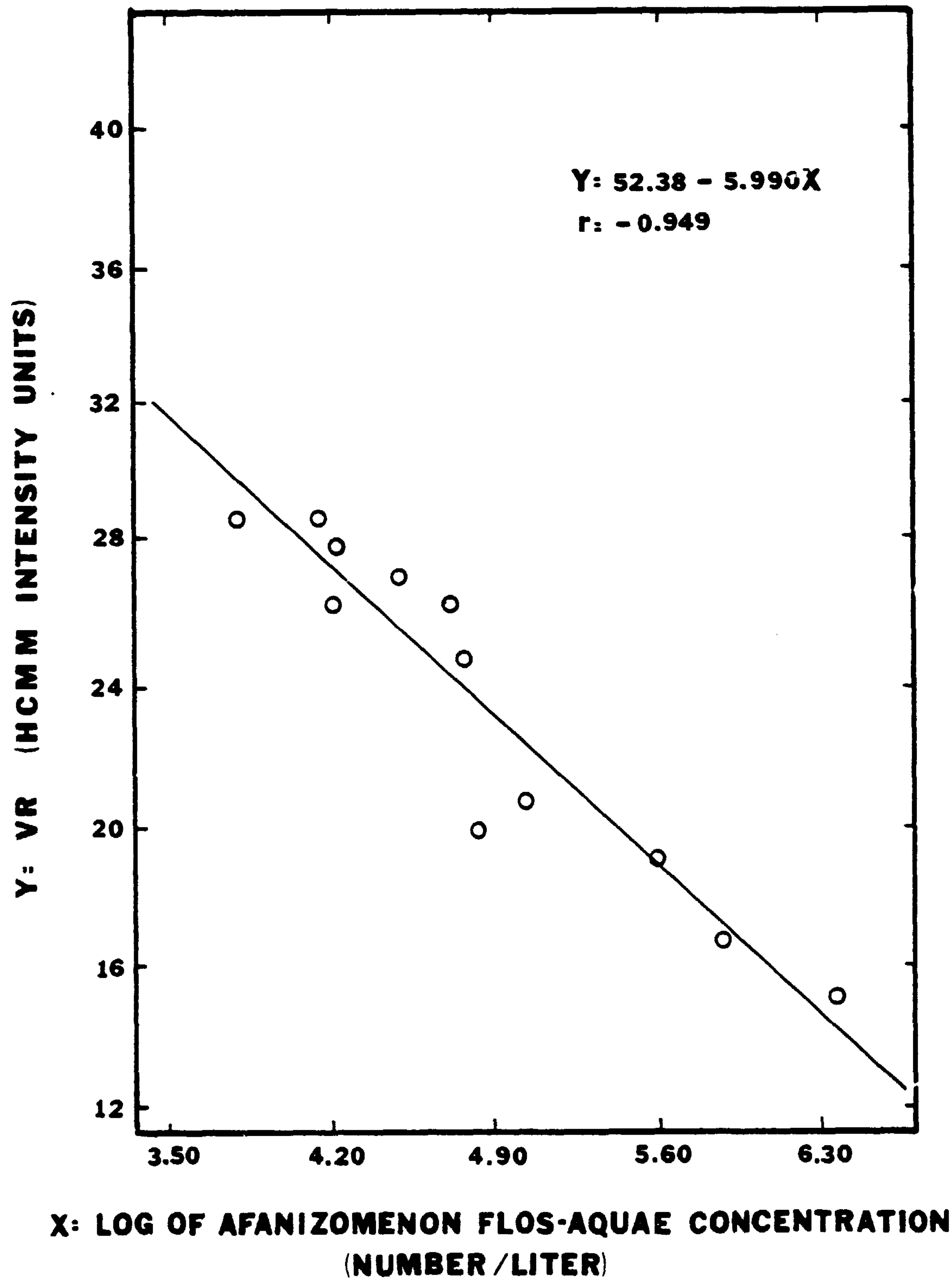

Figure 6. Plot of VR and log of Afanizomenon flos-aquae concentrations on Utah Lake, August 10, 1978.

on Utah Lake have been compiled by date of sampling and will be included in the final report. Table 2a gives the correlations and significance of the phosphorus and plankton concentrations.

Table 2a

Correlation Coefficients of Phosphorus and log of the Total Plankton Concentrations

	DIR and log Total Plankton			DIP and log Afanizomenon	
Date	07/28/78	03/10/79	05/12/79	07/28/78	05/12/79
Corr.	0.488	0.566	0.725	0.864	0.384
Sig. (α)	n/s	0.05	0.01	0.005	n/s

These correlations indicate that at least in the first half of the year the plankton concentration in Utah Lake is dependent on the concentration of phosphorus present. This was to be expected since phosphorus is a basic nutrient of nearly all blue-green algae. There were only two dates on which data was available to analyze the correlation between the phosphorus concentrations and Afanizomenon concentrations in Utah Lake. Therefore, it is difficult to determine any meaningful relationship from these results.

Nitrogen and log of Total Plankton Concentration

Analyses were performed in the Brigham Young University Water Research Laboratory on water samples taken at testing stations on Utah Lake in order to determine the concentration of nitrogen in the samples. The nitrogen present was classified as ammonia, nitrite or nitrate. Results of these analyses were recorded in the unpublished Utah Lake research laboratory reports. The total of the nitrogen measurements

which coincide with algae and HCMM measurements made on Utah Lake have been compiled by date of sampling and will be tabulated in the final report. Correlations of these measurements are shown in Table 2b

Table 2b

Correlation Coefficients of Nitrogen and the log of the Total Plankton Concentrations

Date	07/28/78	03/10/79	05/12/79
Corr.	0.688	0.556	-0.066
Sig. (α)	0.025	0.05	n/s

Nitrogen is a nutrient necessary for algae growth; however, the results of this correlation analysis are inconclusive. This is because there were only a few days on which measurements were made of both nitrogen and algae concentrations.

Turbidity and log of Total Plankton Concentration

Turbidity is the measure of opacity or light scattering properties of the water sample. Records of the turbidity measurements made are recorded in the unpublished Utah Lake research laboratory reports. These measurements were made on an Hach, Model 2100A, Turbidimeter in the Brigham Young University Water Research Laboratory. This meter measures in Nephelometric Turbidity Units (NTU) which are a measure of the intensity of the light scattered in the sample at an angle of 90 from the direction of the incident light source. The measurements which coincide with the algae and HCMM measurements made

on Utah Lake have been compiled by date of sampling and will be included in the final report. Correlations of these measures are presented in Table 5.3a.

Table 3a

Correlation Coefficients of Turbidity and the log of the Total Plankton Concentration

Date	07/28/78	03/10/79
Corr.	-0.121	0.520
Sig. (α)	n/s	n/s

There does not appear to be any significant correlation between the turbidity of the water samples and the concentration of the plankton in them. This may be explained by several factors. First, Utah Lake is a very shallow lake so winds cause complete turnover in the lake waters and stir up into suspension the bottom sediments. These suspended sediments may be principally responsible for the turbidity measured in the water samples. Secondly, the algae present in the water column are not so likely to scatter incident light as suspended solids because they are relatively transparent when not clustered together and allow more light to be passed or refracted than difracted.

Turbidity and Day-Infrared

Table 3b

Correlation Coefficients of DIR and Turbidity

Date	07/28/78	07/10/79	08/24/79	09/22/79
Corr.	0.158	-0.150	0.240	-0.456
Sig. (α)	n/s	n/s	n/s	n/s

Correlations from Table 3b show that the more turbid waters of Utah Lake do not appear to emit any more heat (DIR) than the other waters of the lake. This is consistent with the result that there was no significant correlation between algae concentrations and turbidity.

Visible Reflectivity and Turbidity

Table 3c

Correlation Coefficients of VR and Turbidity

Date	07/28/78	08/31/78	07/10/79	08/24/79	09/22/79
Corr.	0.137	-0.189	0.604	0.090	0.857
Sig.(α)	n/s	n/s	0.025	n/s	n/s

As Table 5.3c shows, there does not appear to be any significant continuous relationship between the reflectivity of Utah Lake and the turbidity of the water. Again, this confirms the results of the correlation between plankton concentrations and turbidity; i.e., that there was no significant relationship between them.

Day-Infrared and Visible Reflectivity

Table 3d

Correlation Coefficients of DIR and VR

Date	07/28/78	08/31/78	07/10/79	08/24/79	09/22/79
Corr.	-0.837	-0.796	-0.628	-0.535	-0.547
Sig.(α)	0.005	0.005	0.025	0.05	0.05

The correlations of Table 3d show a certain level of negative correlation which was expected. These results are simply a

statistical expression of the fact that algae may be presumed to be present in the waters of Utah Lake wherever VR intensities are relatively low.

Night-Infrared and log of Total Plankton Concentration

The HCMM Night-Infrared (NIR) measurements were made by the satellite and tabulated for this comparison as explained previously. The NIR intensity nearest each station where lake measurements were made was recorded and will be included in the final report tables. Table 3e gives the correlations and significance level of the NIR and plankton data.

Table 3e

Correlation Coefficients of NIR and log of the Total Plankton Concentration

Date	08/31/78	09/13/78
Corr.	-0.918	-0.727
Sig.(α)	0.005	0.025

Due to the fact that only a small amount of NIR data was available for this study, only two dates on which NIR and total plankton measurements were made could be used. Data from a few other days was acquired but unusable because of clouds which made the intensity readings inaccurate. The two correlations which were performed however indicate a strong negative relationship between the emitted heat from Utah Lake at night (NIR) and algae concentrations in the lake waters. This result agrees with the observation made with respect to the correlation of DIR and plankton concentrations, that waters with

significant suspended algae mass behave in a similar manner to the surrounding land. They heat up more quickly than the clear waters in the daytime and cool more quickly at night. Figure 7 shows a plot of the linear regression of the NIR and the log of Total Plankton Count on Utah Lake, August 31, 1978.

Evaporation Analyses

The relationships among algae, windspeed, air and surface temperatures, evaporation, and HCMM data were also investigated during the third quarter.

Evaporation Equations

Evaporation is of such importance in the analysis and design of water works that much research has been directed to this effort over the past decades. As the amount of data available has been historically small, great effort has been made to find suitable relationships that will minimize the need for extensive climatological data. One of the first equations developed was the so called Dalton Equation which involves an impirical wind speed function. The typical form is:

$$E = (e_s - e_d)f(u)$$

where E = evaporation per unit time, usually inches per day.
e_s = vapor pressure at the evaporating surface.
e_d = vapor pressure in the atmosphere above.
$f(u)$ = function of the horizontal wind velocity of the form $a + bu$, where a and b are constants and u is the wind speed.

Other variations of this equation have been developed (Rohwer, 1931) and many forms of the wind speed function relationship have been used in the derivation of yet other equations. The above equation was

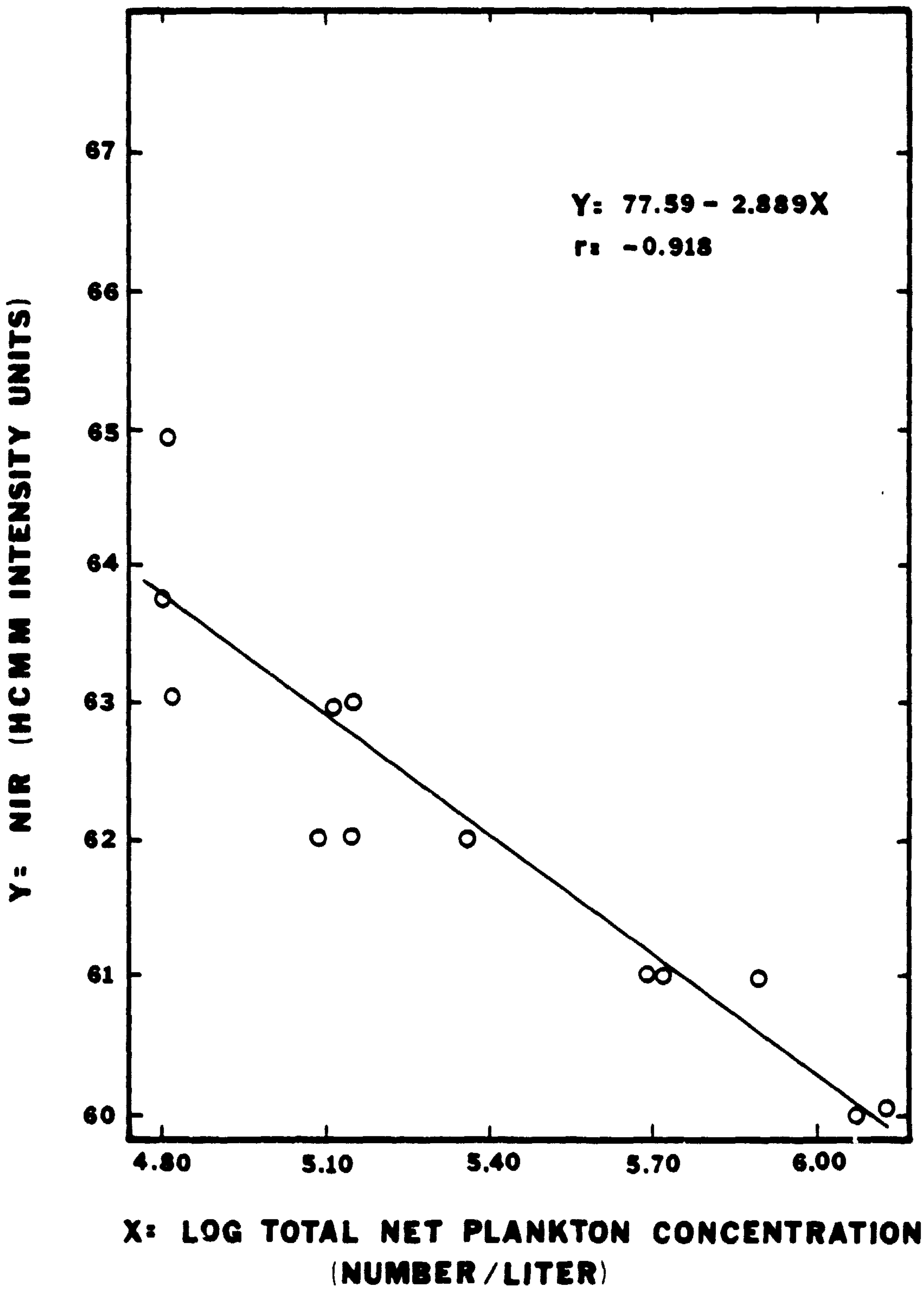

Figure 7. Plot of NIR and log of Total Plankton Concentrations on Utah Lake, August 31, 1978.

used in this study because of its simplicity and the ability to use satellite data directly in the calculation of terms in the equation.

Sources of Error

From published literature, there are several sources of error identified. On small bodies of water a change in wind speed has a significant effect upon evaporation. The effect of wind on evaporation decreases with the increasing size of the lake. It is expected that Utah Lake is of sufficient size to be free of the wind effects. Previous studies have given estimates of the pan coefficients.

Energy advected from the lake surface and vapor pressure blanket over the lake affect evaporation. The effect of advected energy in the overall energy budget is known to be small. Vapor pressure measurements can be affected by the vapor pressure blanket over the lake. The location at which vapor pressure measurements are taken with respect to that of the wind can induce a "size effect" into the equation. A variation of f(u) with lake size would be shown even though evaporation were independent of this. The measurement of vapor pressure should be upwind of the lake in air unaffected by the vapor blanket of the lake. The relationship between temperature and saturation vapor pressure is curvilinear and therefore the use of average daily temperatures and dewpoints bias the equation (Kohler, 1955, and 1967).

Data Collection

The data needed were readily available. The satellite imagery gave the surface temperature of the lake with much greater precision than by conventional sampling methods. Humidity data had been collected and tabulated during a previous study and was supplied by the Bureau of

Reclamation. Humidity data was taken on the east side of the lake. This is on the downwind side with respect to the prevailing winds and as such may induce some bias into the relationship. As the purpose of this study is to apply HCMM satellite data to the evaporation model and not primarily to study evaporation, the available data is used with the understanding that the results may have bias.

Evaporation is measured at two sites along the lake, the Bureau of Reclamation (USBR) pan at the Provo Airport and the Utah Lake Lehi weather station. Both have evaporation and wind data and Lehi has pan and air temperature data. Both pans are close to the edge of the lake. Early wind data from Provo is at a height of 38 feet. Later data is from pan height as is the Lehi data. The velocity of wind over water changes relative to that on land and increases depending upon the fetch. As both sites are on the downwind side of the lake, wind velocity measurements will correspond closely to that of wind over water.

The HCMM temperature and the evaporation data were tabulated and yielded fourteen days of usable HCMM day infrared data and five day/night infrared pairs that could be used in the analysis. Lake temperatures were calculated with the HCMM equation and given a predetermined 4.9 degree centigrade offset. The corrected temperature was then used to calculate the saturation vapor pressure of the surface of the lake. Maximum air temperatures from the Lehi station were used in calculating the prevailing vapor pressure, e_d.

Analysis and Results

With the corresponding Lehi pan evaporation, the values for the windspeed function $f(u)=E/(e - e)$ were calculated. These values were plotted against both the Lehi and Provo Airport wind data. Insignificant correlation existed in both cases. A comparison of these preliminary plots with those of others showed that the wind speeds of the HCMM days did not have as great a range as those of Penman. This is probably because the HCMM images are only for days that are clear and relatively calm, being in between storms. Therefore days with high wind speeds did not have corresponding HCMM data and were not studied in this analysis.

Wind Speed Functions

Other ways were explored in which the HCMM data could be used in the evaluation of wind speed functions. The relationship between maximum pan temperature and maximum HCMM lake temperature is seen in Figure 8. It is the result of two wind speed functions, from Lehi pan data and satellite data, being plotted on the same graph.

In the computation of the pan wind speed function the average air temperature and average himidity were used to calculate the dewpoint temperature. From this the vapor pressure of the air, e , is calculated. The maximum pan temperature yielded e , the water surface vapor pressure. Maximum pan temperature was chosen because it corresponds to the HCMM day measurement which is also a maximum temperature. These maximum pan wind speed function values, $f(u)$, were calculated and plotted against the windspeed u in Figure 8.

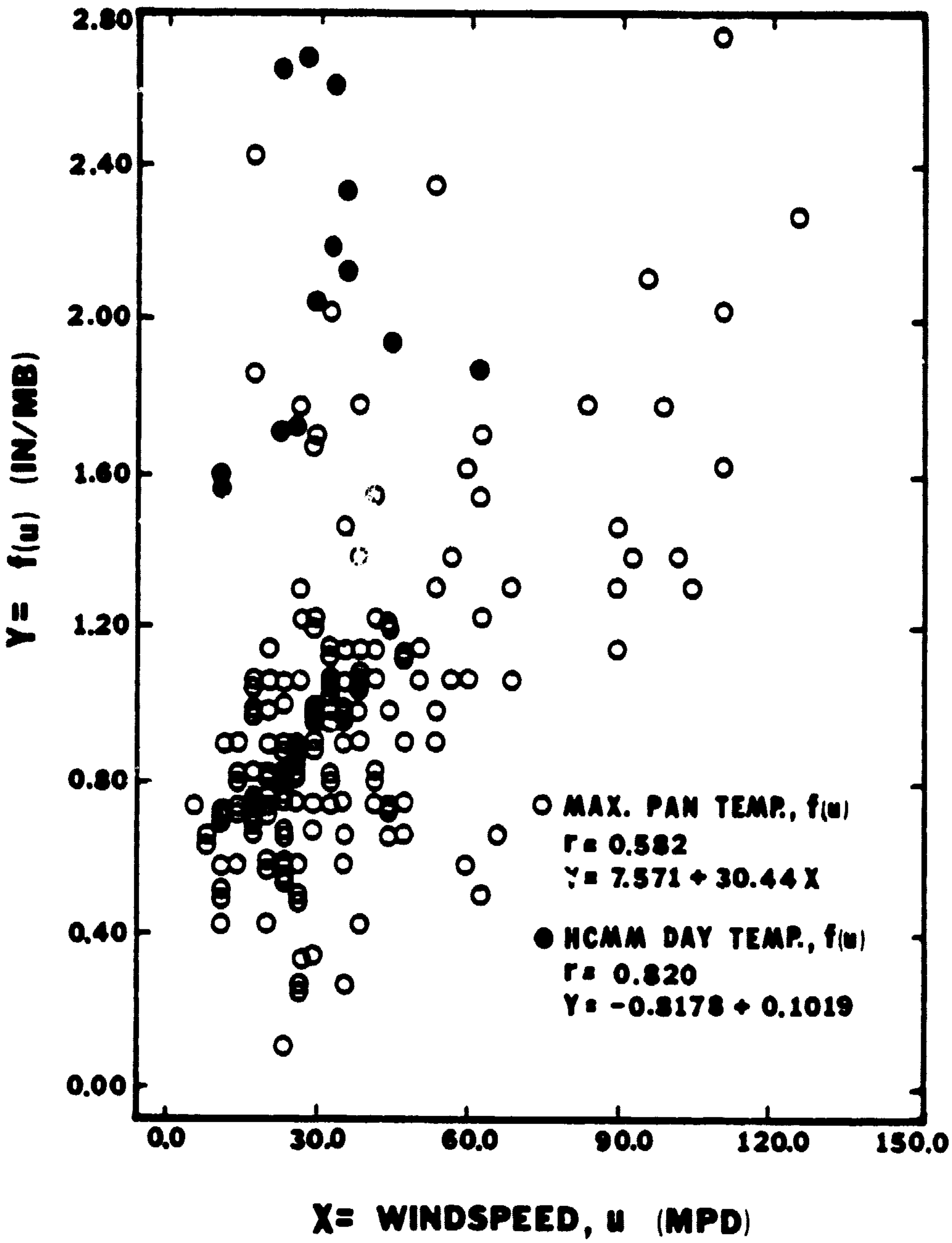

Figure 8. Windspeed Function Y (in/mb) from Max Pan Temperature (C) and from HCMM Day Temperature (C) versus Lehi Evaporation Pan Windspeed u (mpd).

The maximum HCMM windspeed function was calculated with the e as above and Lehi evaporation. The water surface vapor pressure, e , was obtained from the use of HCMM lake temperature data for the fourteen HCMM days. The windspeed functions were then also plotted on Figure 8. Superimposing the two windspeed function in this manner reveals the differences.

The wind speed function values from the HCMM data are much higher than those form the Lehi pan data. This is caused by the difference in temperature of the lake and the pan. For the days studied the pan temperature ranges from seven to fourteen degrees centigrade hotter than the lake. This causes e for the HCMM values to be smaller and therefore gives a larger f(u). Analysis of this difference would be useful in the study of pan coefficients, but is beyond the scope of this study and would require much more frequent satellite coverage of the lake.

The same method of calculation used in Figure 8 is used in the plotting of Figure 9. Evaporation and e are the same as in Figure 8. However, the average pan temperature is used to calculate the water surface vapor pressure, e in the average pan wind speed function.

The average HCMM wind speed function is calculated as above except that the average of the HCMM day and night (DIR a NIR) lake temperature is used in the computation of e and hence f(u). Figure 9 is a plot of the average Lehi windspeed function and the average HCMM windspeed function on the same graph. The superimposed values show that the average lake temperature is slightly lower than the average pan temperature. The average of the five day/night HCMM temperatures yields a windspeed function that plots in the same region of the graph as the

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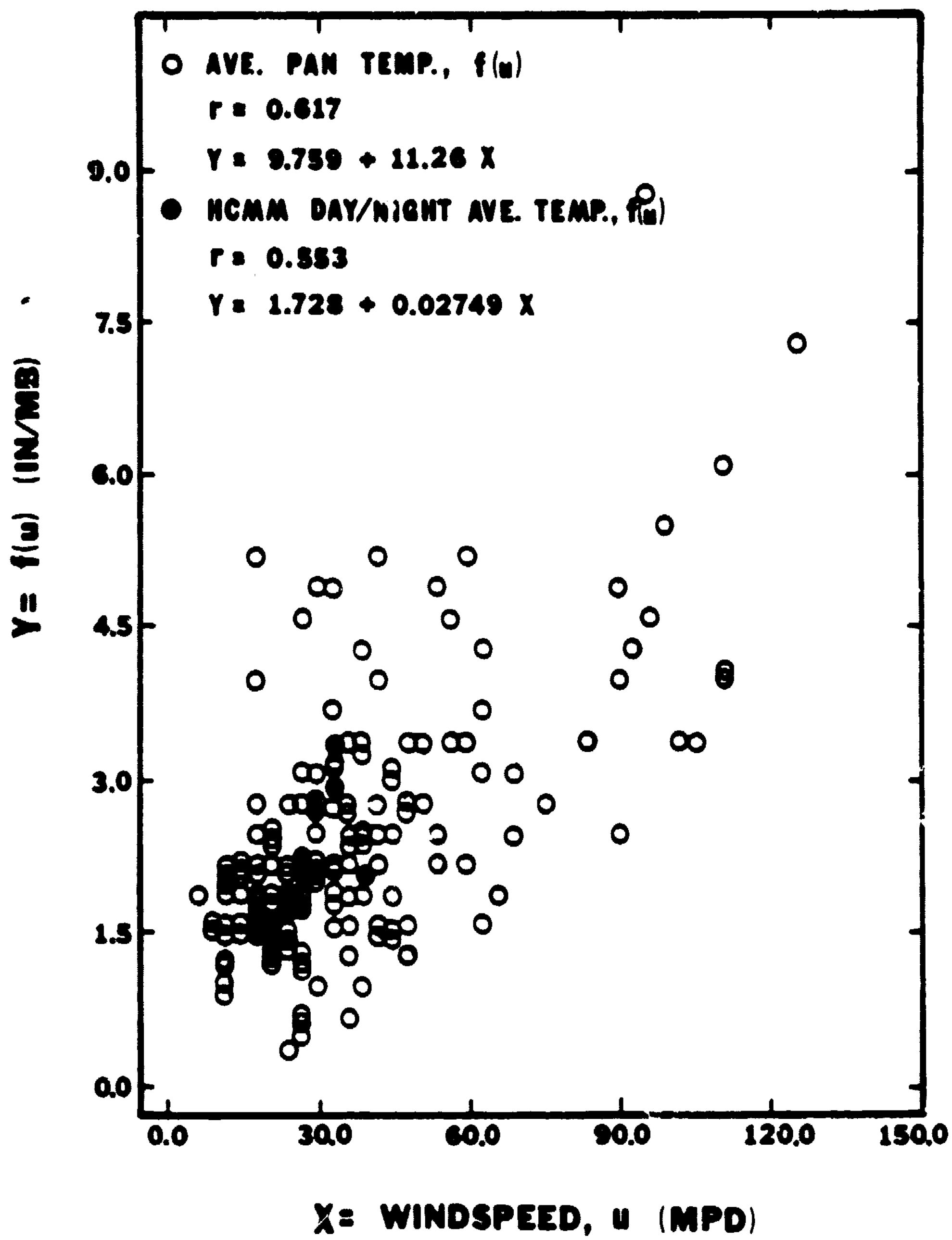

Figure 9. Windspeed Function Y (in/mb) from Average Pan Temperature (C) and from HCMM Day/Night Average Pan Temperature (C) versus Lehi Evaporation Pan Windspeed u (mpd).

Lehi pan data. The study of evaporation and windspeed functions should be with the use of average HCMM temperatures.

Vapor Pressures

An interesting relationship is shown in Figure 10. Three plots are superimposed on the same graph. The first plot is of e (maximum pan) derived from the maximum pan temperature versus e (average pan) derived from the average pan temperature. The second set of points plotted is of e (maximum pan) versus e (HCMM day/night) calculated from the HCMM day/night (DIR/NIR) average temperatures. The final plot is of e (maximum pan) versus e (HCMM day) from the HCMM day infrared (maximum) temperatures.

A comparison of the three plots shows that the e values for the HCMM average temperatures are lower than those calculated from average pan temperature. This was also noted in Figure 10. The vapor pressure calculated from the HCMM day temperature corresponds very well with the vapor pressure calculated from the average pan temperature. It is possible then to use HCMM day data instead of the day/night average.

The agreement between the average pan and the HCMM day values is very useful. Other researchers have shown that a pan 12 feet in diameter has the same evaporation as does a lake. This allows the use of the relatively abundant day infrared satellite data for the study of evaporation.

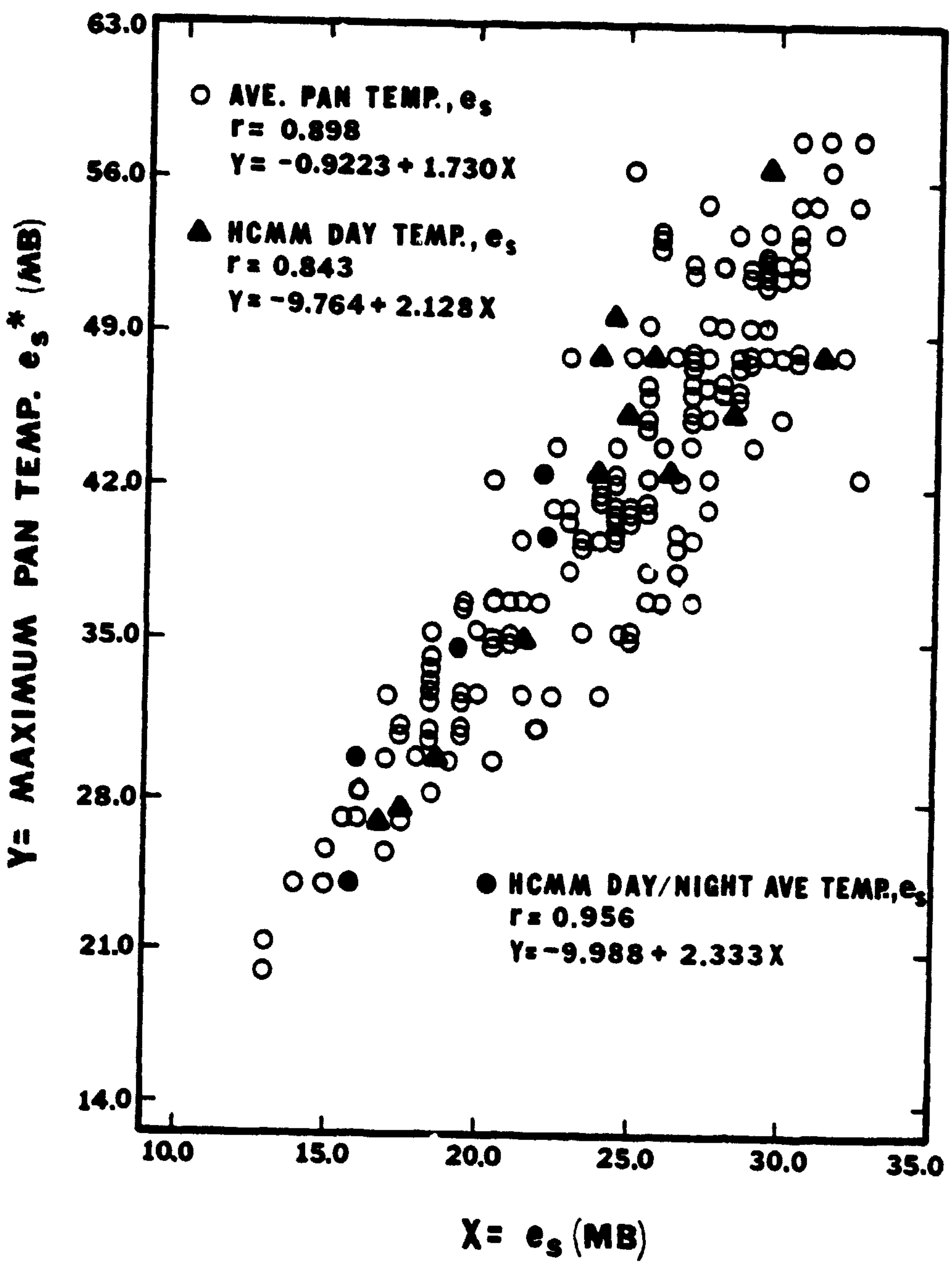

Figure 10. Saturation Vapor Pressure (mb) for Maximum Pan Temperature (C) versus Saturation Vapor Pressure (mb) for Average Pan, HCMM Day, and HCMM Night Temperatures (C).

Evaporation Model

The Utah Lake study gives comparisons of evaporation from several different pans. The pan coefficients were derived using the water budget for the years 1970-1973. The pan evaporation was compared to evaporation from the model developed by F.I. Morton. These data were plotted with respect to the HCMM intensities. Model and pan evaporation was by month; therefore, monthly HCMM averages were calculated using the average lake intensity from the HCMM images. This data, for the years 1978 and 1979, was then plotted against the DIR and the NIR HCMM intensity as seen in Figure 11 and Figure 12.

The correlation for both day and night intensities was excellent. The plot of monthly model and pan evaporation versus DIR showed that 93 and 94 percent respectively of the variation in evaporation could be accounted for by HCMM day intensity. DIR versus daily evaporation gave correlations of only 0.8 to 0.86 as compared to 0.97 for monthly values. As with other methods of evaporation estimation, the shorter the time interval the less accurate are the results.

The plot of evaporation versus NIR shows similiar results (Figure 12). The HCMM night intensity accounts for 95 and 96 percent respectively of the variation in model and pan evaporation. The increase in accuracy by using the larger monthly period for night infrared is very small, from $r = 0.95$ to $r = 0.98$ (Figure 12). This small change in accuracy indicates that estimates of evaporatation for any time period much shorter than a month should be made with the use of HCMM NIR. For periods longer than a month the day intensity is as accurate.

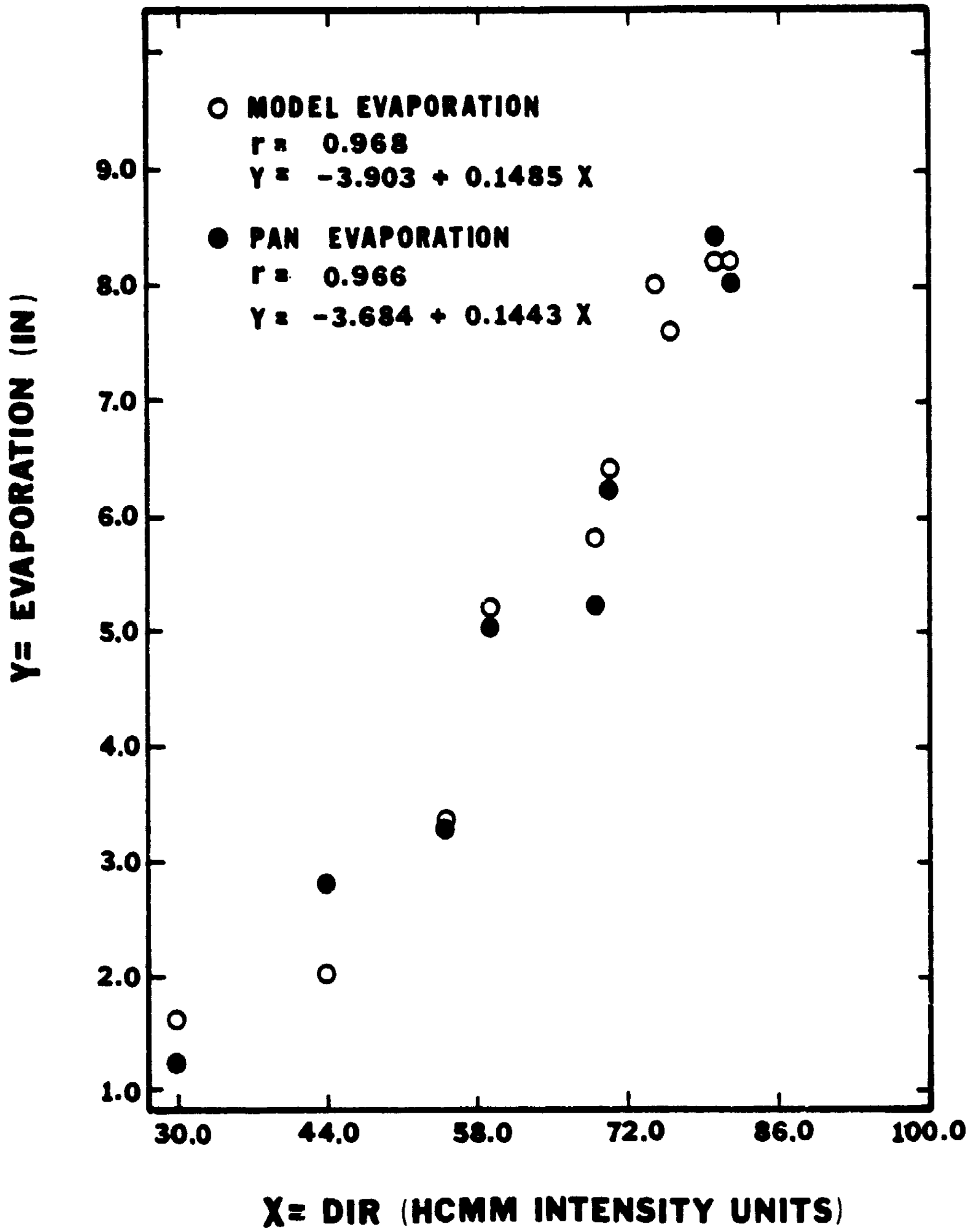

Figure 11. Evaporation (in) versus DIR for Pan and Model Evaporation from Monthly Data.

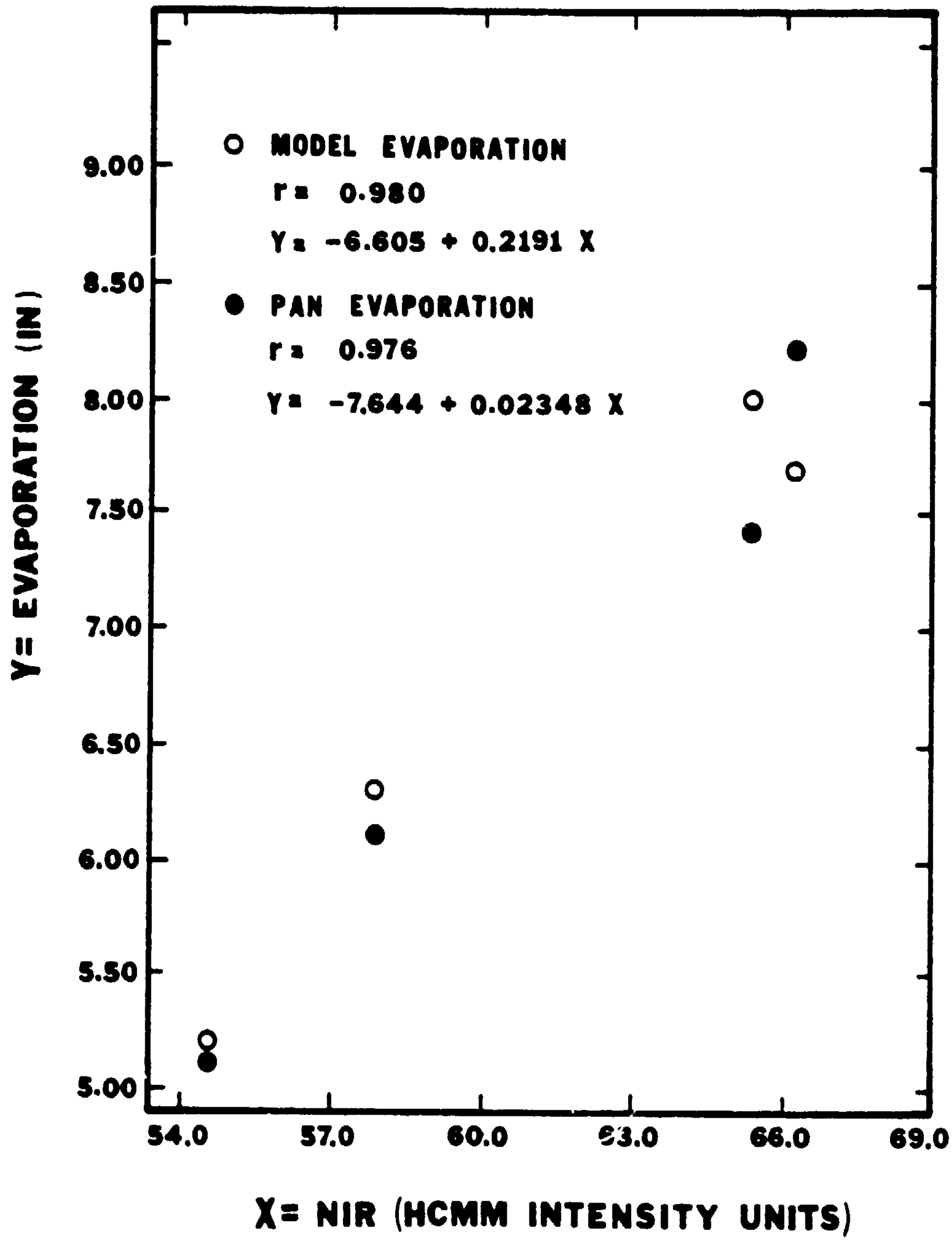

Figure 12. Evaporation (in) versus NIR for Pan and Model Evaporation from Monthly Data.

Evaporation and Algae

For many years the effect of vegetation on evaporation has been studied. The predominant emphasis has been on swamp vegetation varying from reeds to trees. No literature has been found that addresses the subject of algae and evaporation. Though not directly applicable in the present study, results of recent research studies are covered as background material. The effect of algae on water that enables the use of remote sensing is presented herein.

During the summer of 1981 research was conducted to determine the effect of algae on evaporation. Pans were seeded with algae; evaporation, temperature and biomass measurements were taken. Results of this were used to determine the amount that algae changed evaporation. A computer program was written to compare the day visible and infrared images. A false image was formed and displayed on a color graphics terminal. This allowed comparison of the infrared and visible images to determine if there were any consistent pattern or correlation between them.

Algae

Utah Lake is a shallow unstratified eutrophic lake supporting a great variety and amount of life. Succession of plankton species in the lake is seasonal. Early summer species include diatoms and green and blue-green algae including some Aphanizomenon Flos-Aqua and Ceratium Hirundinella. As the environment in the lake changes, Aphanizomenon and

Ceratium become more abundant until at the end of summer they make up approximately 90% of the total flora. The HCMM images are predominantly from July, August, and September, middle to late summer. The effect of algae on evaporation will therefore be caused by Apanizomenon and Ceratium.

Competitive displacement does not proceed at an even rate throughout the lake. Local environmental conditions maintain parts of the lake in a state approximating early summer conditions. Provo Bay, Goshen Bay, and the Provo River inlet area have underwater springs or stream influences that cause development in these areas to lag behind that of the lake. Distribution of algae therefore is not homogeneous.

Wind and currents in the lake also create distribution patterns although it is not known to what extent. From photographs it can be seen that algae forms in wind rows and patches. The windrows could be caused by the upwelling of Langmuir circulation currents where Ceratium Hirundinella would be concentrated. Also promoting accumulations of algae is the prevailing wind. Utah Lake has its long axis in the north-south direction. Climatological data indicates that the prevaling wind for Salt Lake City, 40 miles to the north, usually comes from the south or southwest. This drives the floating algae, Aphanizomenon, into the northern part of the lake.

Although found in the lake at all times of the year, algae can be extremely concentrated in the late summer and form large blooms. These blooms affect the chemistry of the water and cause an increase in water temperature through photosynthetic activity. Many of these stands are essentially unialgal and if more species data had been available it might have been possible to distinguish the type of algae in the bloom

by observing its temperature and reflectance. This would be limited by the fact that a higher concentration of algae is presumed to generate a higher temperature. Use of different wavelengths of day infrared and visual measurements would also be needed for this type of study. The increased temperature of the bloom is easily seen in the day infrared (DIR) image of the 11 September 1979 algae bloom. The temperature of the bloom is elevated by several degrees and the visible reflectance is as great as that of the surrounding land. Mixing within the water column causes a lower reflectance reading but still maintains high temperature. The difference in albedo of floating and entrained algae is not known.

Pan Evaporation

To understand the effect of algae on evaporation, class A evaporation pans with algae growing in them were monitored during the summer of 1981. The Bureau of Reclamation (USBR) evaporation pan is located at the Provo Airport. Adjacent to that enclosure is the B.Y.U. climatological studies enclosure, where the algae pans for this study were located. Therefore the wind, rain and evaporation data to be used in this study were available from the Bureau of Reclamation. The growth of algae in pans should affect the amount of evaporation. The conclusions from this study might then be applied to the lake to give an indication of the effect of algae in the natural environment.

There are several processes blocking or driving evaporation that were of interest. The first consideration was that of the increased pan temperature due to photosynthesis by the algae. This would elevate the

water temperature and cause increased evaporation. The reflectivity of the algae affects the amount of energy absorbed in the pan. The blocking effect of a large mass of floating algae was the third consideration. The photosynthetic effect and the increased absorbtion were expected to increase evaporation noticeably from that of a class A evaporation pan while the blocking action of the algae was expected to be minimal.

Methodology

The size of the enclosure allowed three pans to be placed inside. The fence was of 2" x 4" hogwire. The construction of the stands and their installation was in accordance with U.S. Weather Bureau instructions and matched that of the Bureau of Reclamation (USBR) pan nearby. By this method any error due to difference in installation was climinated and the USBR pan measurements was used as a control in the experiment.

Measurement of evaporation was done with standard stilling wells installed in every pan and the use of a hook gage. The hook gage gave readings to the nearest thousandth of an inch. The same hook gage was used for reading each pan, eliminating error in the use of different instruments. The measurements were read and the pans were filled at 10 a.m. each day.

Thermometers were used in two of the pans to record the high and low temperatures. These were reset each day by the use of a small magnet. The 10 a.m. check of evaporation was late enough in the day that the thermometers could be reset to a low enough temperature that the next nights minimum and the day's maximum would move the indicators

and give a correct reading. The thermometers rested in the bottom of the pan and were usually read in place and then lifted out and reset. When the algae was thick the thermometers had to be lifted out and read immediately, the south side of the bottom of the pan was shaded during most of the day and was where the thermometers were placed in order to give on accurate reading of the water temperature.

Sampling

Evaporation from the pan occurs at the air-water interface and the algae studied was a floating variety. The samples were taken from the surface. Concentration of algae varied over the surface of the pan. In addition, the wind would on occasion cause the algae to concentrate on one side of the pan. Sampling was done with a one quart plastic bottle. The mouth of the bottle was lowered into the water to a depth of about 5 mm and the bottle was drawn across the pan at a uniform rate. The pattern used to sample was that of several straight lines. This ensured that the sample would be representative regardless of the variation in concentration. On those days that the concentration of algae was uniform a triangular pattern was used.

The samples were taken to the B.Y.U. Environmental Analysis Laboratory and frozen. They were later thawed and tested for biomass. Each sample was homogenized and a part put into a vial and centrifuged. The supernatant was drawn off and the algae washed into an evaporation dish. The water was driven out by heating to 103 C for at least eight hours. The dishes were weighed and the biomass calculated as mg/l.

Algae Growth

The early summer algae growth was from an innoculation. The pans were prepared by filling them with water and adding a nutrient solution. Discussions with Dr. Samuel Rushforth (B.Y.U. Botany Department) and Dr. Sigrid Klein (B.Y.U. Chemistry Department) indicated that a standard Allen's nutrient solution would be satisfactory. Allen's solution was added to the pan at the same time as the water and allowed to set overnight. A sample of Anabaena Flos-Aqua, another prominent algae species in Utah Lake was introduced into one of the pans in order to obtain a unialgal culture. The algae did not grow. A larger sample of Anabaena was reseeded into the same pan while the other two pans were seeded with algae taken from Provo Bay.

The object of this proceedure was to grow algae in the pan and take samples as it grew from a small to a large concentration. The water turned green and the algae mixed in the water olumn, but no large surface concentration was formed. The Anabaena Flos-Aqua grew even less than the algae in the pans seeded from lake water. During the later part of the summer when the lake was very active, algae was collected and the pans were stocked with this lake algae once a week using a quantity large enough to cause a high surface concentration.

Errors

Several phases of the data collection could have introduced errors into the study. Variation in the time that the evaporation in the pans was sampled would give erroneous readings. The sampling time of 10 a.m. was just before the major evaporation of the day took place.

Therefore, the error resulting from the variation in the sample time was reduced. Any sample time that greatly differed from 10 a.m. was noted and the evaporation of the Bureau control pan was extracted for that period from the continous forms.

The use of the USBR pan as the contol pan was in itself a major source of error. The pan was filled with water approximately once a week and the measurements of evaporation and rain were recorded on charts with a continuous recorder. The varying water level of the pan effected the amount of evaporation. Calculating evaporation from the strip charts was fairly reliable except during periods of rain. Because of this, all data during times of precipitation was disgarded.

Sampling and determination of biomass was standardized as much as possible. The collection of the sample was the least reliable proceedure. The mouth of the bottle had to be immersed the same amount each time and the speed with which it was drawn across the water had to be held as constant as possible. To reduce the amount of error, the same size bottles were used to obtain all samples. Also the same person took all the samples so that variation caused by different techniques would not be present.

The centrifuge used to concentrate the algae would sometimes leave small pieces floating in the supernatant. Care was taken in this process and finally another more powerful machine was used. Error introduced in this proceedure was considered minimal.

Results

Temperature was known to be increased by masses of algae in the lake. Pan temperatures were taken infrequently in the USBR pan. A comparison of the temperatures of the pans showed that the pans with algae had a smaller change in temperature from minimum to maximum. The amount of evaporation during this period did not vary significantly from pan to pan. The lack of difference in total evaporation indicated that the amount of algae in the pans had no significant effect on evaporation. The top of the pans were covered with algae when many of the samples were taken. Table 4 shows a histogram of the middle of the interval of the log of the algae biomass concentration and the number of observations in each interval. The range of biomass data is large enough that any effect on evaporation would have been shown.

Table 4. Histogram of the Middle of the Interval and the Number of Observations of the Logrithim of the Algae Biomass (mg/l).

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
1.6	1	*
1.8	1	*
2.0	6	******
2.2	6	******
2.4	7	*******
2.6	10	**********
2.8	5	*****
3.0	8	********
3.2	3	***
3.4	5	*****
3.6	1	*
3.8	0	
4.0	1	*

The amount of evaporation did not depend on the amount of algae present. The separate effects of differing albedo, photosynthesis, and blocking could not be determined. Figures 13 and 14 show the change in evaporation versus the log of the algae biomass concentration using both the USBR pan and the B.Y.U. weather station pan on the B.Y.U. campus. The correlation coefficients were almost zero and the regression lines were virtually horizontal.

The plots from the B.Y.U. and the USBR pans are similar except for the differing intercepts of the Y-axes. From this it is concluded that any of the effects of algae on evaporation cancel each other with no net effect on evaporation. The use of B.Y.U. data results in a different intercept because the B.Y.U. pan is located over 5 miles from the lake. This shows that though the location of the pan may be different, the regression line is virtually horizontal, showing no correlation of algae and evaporation.

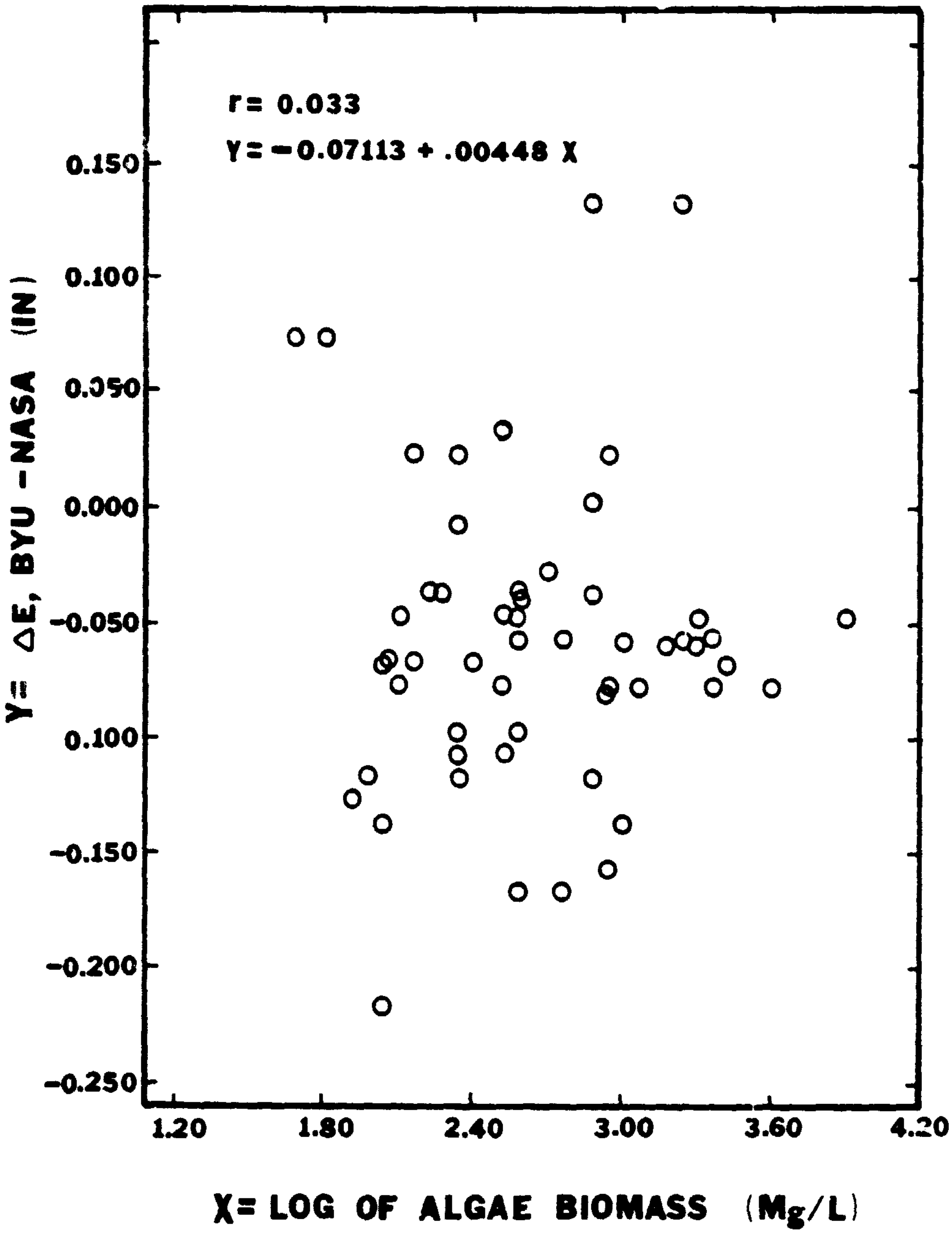

Figure 13. Difference in Pan Evaporation, BYU Weather Station Pan minus NASA Pan, versus the Log of the Algae Biomass (mg/l)

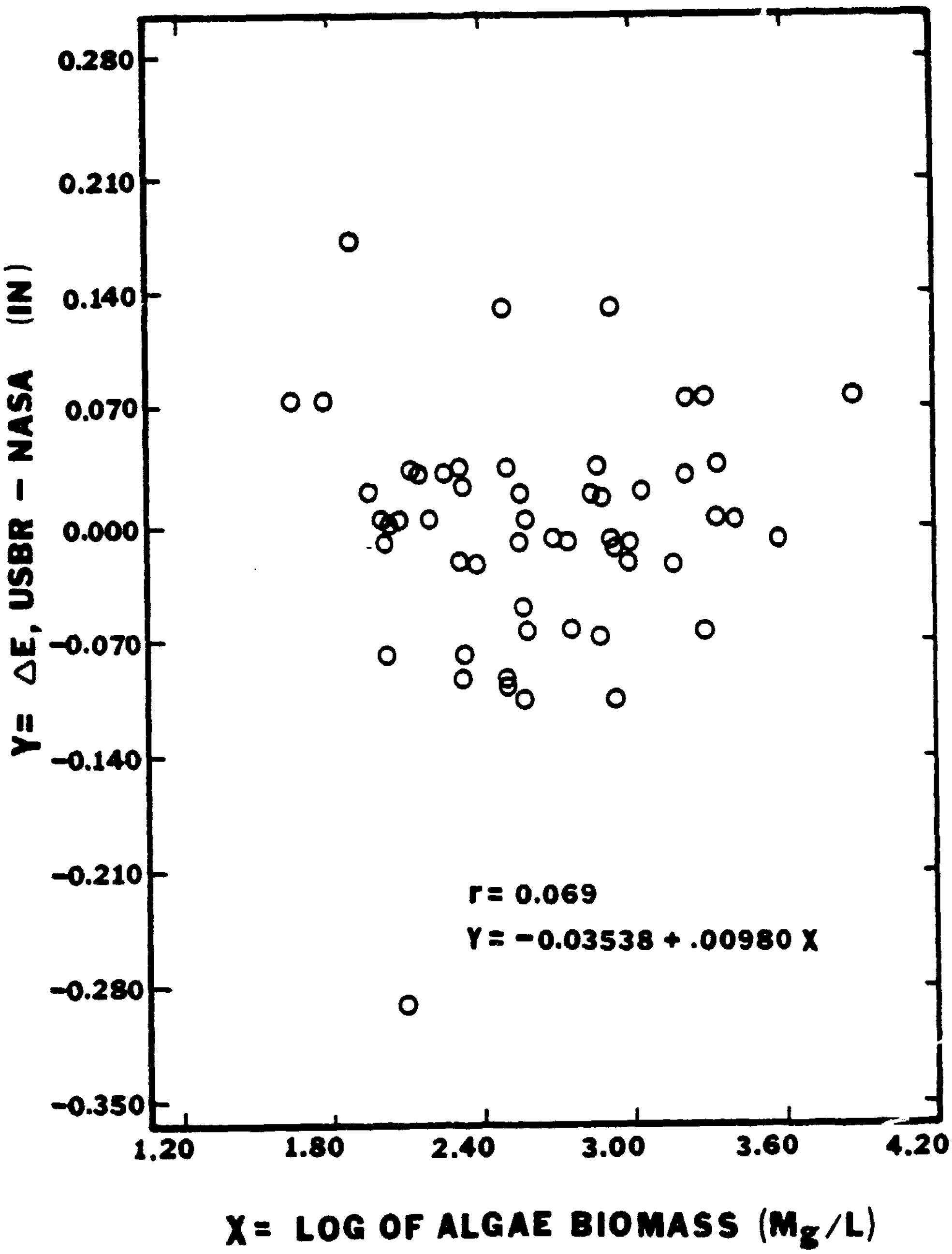

Figure 14. Difference in Pan Evaporation, Bureau of Reclamation Pan minus NASA Pan, versus the Log of the Algae Biomass (mg/l).